MORPHOMETRICS OF WESTERN AUSTRALIAN ABORIGINAL SKULLS

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ABSTRACT

A sample of 105 crania and 53 mandibles from Aboriginal Western Australians has been studied by univariate and multivariate techniques. Fifty cranial dimensions, 22 derived indices and 18 mandibular measurements were analysed for sexual dimorphism and regional differences. Comparisons were also made with data from similar studies of samples from Western Australia and coastal New South Wales.

Most of the measurements and indices studied showed significant sexual dimorphism and hence, for further analysis, the sexes were analysed separately. The material was subdivided on broad linguistic criteria. Canonical analysis indicated clinal variation in the 3 coastal samples, with the single inland sample markedly divergent. The main discriminating features have been analysed.

A generalised distance analysis of the 4 Western Australian and 3 coastal New South Wales samples revealed an interesting pattern. The northern samples of the 2 States were most similar, and the central and southern samples showed progressively higher D^2 values from their own State northern sample and also from the opposite State equivalent. Such a set of relationships would seem to indicate an initial northern Australian colonisation by a single stock followed by migration down the east and west coasts.

INTRODUCTION

Starting in the 19th century (e.g. summary by Turner, 1884) a large number of metrical studies have been made of Australian Aboriginal skulls and

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interest continues (e.g. Howells, 1970; Brown, 1973). In most of the earlier studies, the samples of skulls analysed from the various parts of Australia were small, but more recently, some substantial samples from the eastern States have been analysed (e.g. Freedman, 1964; Giles, 1976). However, in all of the metrical studies so far made the number of specimens from Western Australia, which in area comprises just under one third of the continent, has never exceeded 30. Of the many previous studies only two have dealt specifically with Western Australia. Woodward (1901) examined 16 crania using 16 measurements and indices, while Bourne and Mulcahy (1935) published cranial indices for 30 unsexed crania. Apart from these two reports, reference to Western Australian crania has been restricted to small numbers (8-17) which were studied as parts of Australia-wide analyses (e.g. Morant, 1927; Hrdlicka, 1928; Wagner, 1937). With regard to non-metrical cranial studies, Kellock and Parsons (1970) studied 73 unsexed Western Australian crania by multivariate analysis.

The long settlement of Western Australia by the Australian Aborigines has recently been confirmed by excavations at Devil's Lair in the extreme south west of Western Australia. The cave has been radiocarbon dated as a human occupation site back to 24,600 ± 800 yrs B.P. (Dortch and Merrilees, 1973). This considerable antiquity, coupled with the very substantial area of Western Australia (close to 1 mil. sq. mls), makes Aboriginal skeletal material from this State very important for studies of the origin, variation and the much debated entry and migration routes of the Australian Aborigines.

The specific aim of the present study was to fully describe metrically 105 crania and 53 associated mandibles from Western Australia. The material was studied by uni- and multivariate analysis, as a whole and in subsections, males and females always being treated separately. Comparisons were also made to some of the previously described series of Aboriginal crania from Western Australia (Morant, 1927; Hrdlicka, 1928; Wagner, 1937) and also from coastal New South Wales (Freedman, 1964).

MATERIALS

The sample of Western Australian skulls analysed included: 84 crania and 41 mandibles from the Western Australian Museum, Perth; 17 crania and 9 mandibles from the South Australian Museum, Adelaide; and 4 crania and 3 mandibles from the Department of Anatomy and Human Biology, University of Western Australia, Perth. The material was generally in good condition, with the exception of the zygomatic arch, which was often damaged or lost — generally only unilaterally; also, many teeth were missing, usually due to post-mortem loss. Post-cranial material was available in only a few cases and, of these, only four included appropriate parts (pelves and femora) for confirmatory sex determination. The localities of the specimens used are shown in Fig. 1.

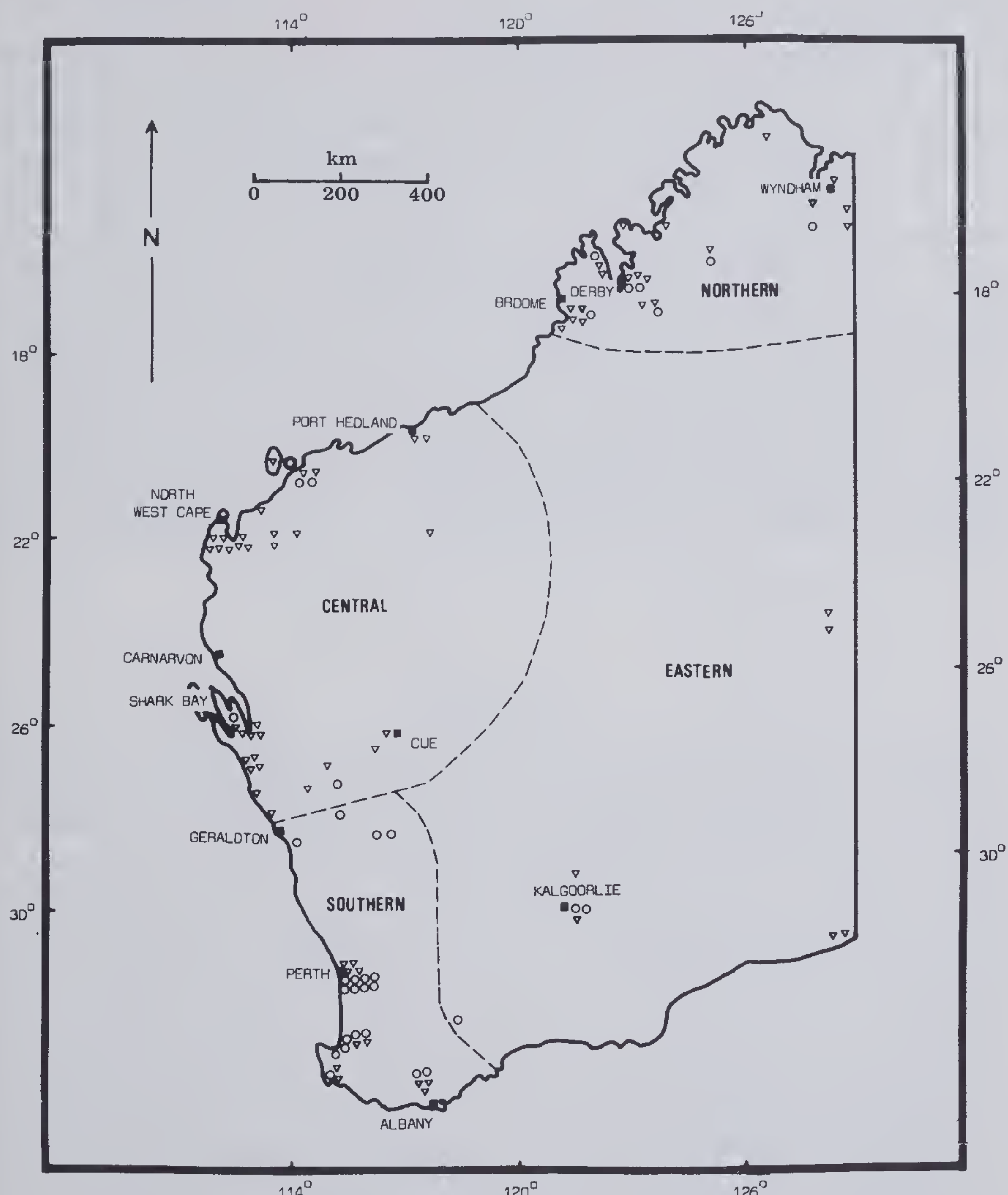

Fig. 1: Map of Western Australia giving the localities of the skulls studied, and the boundaries of the samples analysed. ▽ = males; o = females.

Because the material used was derived from museum collections several problems must be noted. Most of the specimens were recovered from chance discoveries of burials which had been exposed either by weathering or during building excavations. Thus, all of the specimens had to be carefully examined and assessed as Aboriginal, mainly on overall morphological appearance, but also on the records relating to the find. The recorded location of each specimen had also to be accepted in plotting the distribution of the material in Fig. 1. These records have mainly relied upon the original finder recalling, often quite some time later, precisely where, when and with what associated material the specimen was found, and then someone recording the information. Errors in both of these steps may have occurred. A further problem was that the material was assumed to be of recent origin but may in fact range over a quite considerable time span. No radiometric or other dates were available for any of the material used in this study. Finally, as Gill (1968) has noted, p. 213, "there is a selection factor in the preservation of human crania whereby the stronger ones will tend to be preserved and the weaker ones destroyed". This, plus any initial selection for burial, may constitute further possible sources of bias when postulating this sample as representing the recent Aboriginal population of Western Australia. However, similar strictures probably apply to all excavated Australian Aboriginal skull samples.

METHODS

Initially 77 of the crania were sexed by the method developed by Larnach and Freedman (1964). The results are shown in Table 1. In the remaining 28 crania one or more of the features used in the technique was damaged or missing. For these crania the sex was decided by substituting first male and then female mean values for those missing. By this method, confirmed by a detailed study of overall cranial form, it was possible to confidently determine the sex of all of the crania in this group. In the four crania with post-cranial material appropriate for sexing, the subpubic angle, the shape of the sciatic notch, the size of the femoral head and the angle of the femoral neck were examined (Davivongs, 1963). The three crania marked with a plus sign in Table 1 had their sexes confirmed by the post-cranial material. For one specimen (589 — marked with an "X") post-cranial sexing (female) did not confirm cranial sex determination (male). On cranial sexing the value found for this specimen was 12, the lowest male value for the technique. After a full re-assessment, it was decided that the specimen was best regarded as a

Table 1: Scores for 77 Aboriginal crania of known provenance from Western Australia using the 7 character sexing method of Larnach and Freedman (1964).

7	8	9	10	11	12	13	14	15	16	17	18	19	20
									248				
									1348				
				FEMALE	MALE		244		3976				
							1149		4968				
							6071	233	8907				
							10318	234	8965^{+}				
				247			12055	838	15504				
				KAR.2			16002	3978	16343^{+}		241		
			666	5860			16053	8964	22692		243		
	235		4969	9550			16256	11333	22693		10247		
	242		22687	15347		585	16980	13196	22836	656	K		
	9582		22737	15815^{+}		839	25425	22690	25422	16259	15505		
	9988		25423	22689	589^{x}	5107	25475	22691	25569	16261	N.W.C.		231
4686	15349	38698	25521	25424	9987	8540	38699	22835	KAR.1	25474	25619	5884	25471

+ Confirmed by post-cranial skeleton

x Post-cranial skeleton female

female for this study. As a check on the Larnach and Freedman (1964) sexing technique, several crania on either side of the sectioning point, i.e. 11 (female) or 12 (male), were sexed using the discriminant function number 3 of Giles and Elliott (1963). The sectioning point for the discriminant was taken from Larnach and Freedman (1964). In each case (including 589) the assigned sex agreed with the sex determination by the Larnach and Freedman technique.

For purposes of analysis, the Western Australian material was first studied as a group and then subdivided into 4 regional samples (Fig. 1: northern, central, southern and eastern), mainly on the basis of linguistic features. Capell (1956) has divided the Australian Aborigines into two broad linguistic subgroups. Those using prefixing languages are found in the northern one-eighth of the continent, whilst those using suffixing languages are spread over the remaining seven-eights of the continent. In Western Australia the prefixing group extends southward to the Western Desert. This region forms the northern sample of this study. The remainder of Western Australia is populated basically by Aboriginals using a suffixing type of language. However, within this group Capell (1956) has demonstrated varying word order structures. The Western Desert, forming the eastern sample, has an elastic word order which differentiates it from the more restricted word order found along the coastal region. The coastal subdivision between the central and southern group (just north of Geraldton) was somewhat arbitrarily decided upon after consideration of more minor linguistic and other features.

For the available material the above subdivisions would appear to produce the most likely social groupings of the individuals whose skulls have been measured. However, to test for finer micro-evolutionary variations, the northern and central samples were further subdivided into seven subsamples. For descriptive purposes these may conveniently be considered as located around (Fig. 1): Wyndham, Derby and Broome (= northern); and Port Hedland, North West Cape, Shark Bay and Cue (= central).

In the present study 50 cranial and 18 mandibular measurements were made. This rather large number was taken in order to make the data comparable with those studies with which it was intended to compare the material. From the cranial measurements 22 indices and ratios were calculated, several of these (e.g. chord/arc) being specifically aimed at describing bone shapes. The measurements and indices used are mainly from Martin and Saller (1957), Howells (1973), Thorne (1976), and Freedman and Wood (1977). Measurements were made with standard anthropometric instruments and were recorded to the nearest millimetre, except in the case of small measurements (e.g. orbit and foramen magnum) which were recorded to the nearest 0.1 mm. For the mandibular dimensions most of the measurements were made with a mandibulometer. For accurate and comparable measurements we believe the use of this instrument is essential.

To examine observer variation in recording measurements 6 crania were selected at random and measured on two separate occasions. The method of analysis of observer variation used followed Brown (1973). Mean differences and standard errors of the mean differences for the 6 pairs of each measurement were calculated and, from these, 't' values were computed. Of the 50 measurements recorded for the cranium only two were significant at the 5% level of probability; both of these, mastoid height and bi-stephanion, presented technical difficulties because of the variable position of the landmarks used.

The univariate statistics for the cranial and mandibular measurements and indices were computed on the Cyber 72 computer of the University of Western Australia, using the Statistical Package for Social Sciences (S.P.S.S.) Program (Nie, Bent and Hull, 1970). Results are presented, or/and discussed, separately for males and females, for each of the samples studied. In each case the number (N), the mean ($\overline{X}$), standard deviation (S.D.), coefficient of variation (C.V.) and observed range (O.R.) was computed. In addition 't' test values for male-female comparisons were calculated.

To compare and contrast the various Western Australian subgroups the data were also analysed by multivariate techniques. The male samples were studied using all 50 cranial measurements and also in parts, i.e. face, vault and base separately. The male cranial indices and the mandibular dimensions were also examined by multivariate methods. In addition, the 4 male Western Australian samples were compared with 3 male coastal samples from New South Wales (Freedman, 1964). Because of the small numbers and uneven distribution of the female material, the only multivariate analysis made was a 15 variable study of the crania. The programme used on the Cyber 72 computer was MULVAR, kindly provided by N.A. Campbell, Mathematics and Statistics Division, Commonwealth Scientific and Industrial Research Organisation, Perth.

The two multivariate techniques utilised were canonical variate analysis and Mahalanobis generalised distance (Blackith and Reyment, 1971). Canonical variate analysis uses standardised and orthogonal variables to maximise the ratio of between to within population variance. It thus maximises the effect of those variables, or combinations of variables, leading to inter-population differences, relative to the within population variation. The second multivariate statistic, Mahalanobis generalised distance, may be considered to be the distance between the canonical variate means, as measured in multidimensional space. It thus takes into consideration interdependence and expresses the standardised distance between population means in a single measure, the D^2 value. The principles and methodology of these techniques are described in detail in the reference cited.

RESULTS

(1) Univariate analyses

The basic statistics of the 50 measurements for the Western Australian crania are listed separately for males and females in Table 2. Inspection of the data and coefficients of kurtosis and skewness (calculated but not included) suggest that most of the measurements were normally distributed.

The most important exceptions to normality of distribution, in both males and females, are in the small cranial dimensions involving the opisthocranion and inion. Both of these points are variable in their location, and opisthocranion may even be found at more than one point. The coefficients of variation for measurements involving these points are high, and this is especially so for both sexes in the case of lambda — opisthocranion (male, 37.54%; female 33.76%). The only other markedly high coefficients of variation in both sexes are palatal height (male, 18.55%; female 17.37%) and, to a lesser extent, mastoid height (male, 11.90%; female 11.55%). Palatal height variation probably stems from the tendency for torus or trough formation at the intermaxillary suture; for mastoid height there is difficulty in ensuring consistency in the selection of the uppermost point which should be on the Frankfurt Plane. Nasion — nasospinale (male, 11.70%; female, 10.50%) tends also to have a high coefficient of variation due to some difficulty in locating the inferior point for the measurement.

The male-female 't' test comparison is significant at the 5% level in all but one instance (foramen magnum breadth). Further, in only two instances (bi-infratemporal breadth and lambda-opisthocranion) is the probability level not below the 0.1% level.

The statistics of the 22 cranial indices for the Western Australian males and females are listed in Table 3. Three indices in both males and females are extremely variable and hence have very high coefficients of variation. These are: supra-orbital breadth/bi-frontosphenoidale (male 62.82%; female, 56.30%), supra-orbital breadth/bi-frontotemporale (male, 35.76%; female, 40.21%) and bi-malar breadth (male, 34.60%; female, 35.73%). In addition, the coefficient of variation for the nasal index in both sexes is also somewhat large (male, 15.00%; female, 15.10%). Males and females differ significantly (5% level) in 20/22 indices. Except in two instances, orbital and gnathic indices, the 't' test probability levels are all less than 1% and 16 of these are at less than the 0.1% level.

Table 4 lists the basic statistics for the 18 measurements of the male and female Western Australian mandibles. A number of coefficients of variation are on the high side and this is especially so in both sexes for sigmoid notch depth (male — 13.58%; female — 18.78%) and corpus breadth (male — 12.88%; female — 13.87%). The male corpus height (16.95%) and the female symphyseal breadth (15.91%) are likewise high. All male-female 't' test comparisons for mandibular dimensions are significant at greater than the 0.1% level.

The basic statistics of the 4 male Western Australian samples, for the 15 measurements used in the multivariate analyses comparing these samples with those from coastal New South Wales (Freedman, 1964), are tabulated in Table 5. Table 6 includes the statistics for some other important highly weighted measurements (and derived indices) found in the 4 sample Western Australian canonical analysis. These two sets of univariate statistics will be discussed together with the multivariate data.

(2) Multivariate analyses

(A) Canonical variate analysis

(a) Whole cranium, 50 variables, 4 male Western Australian samples

Table 7 lists the mean scores on the 3 canonical variates for the 4 samples and also the canonical roots and percentages of the variance accounted for by each of the variates. The mean scores on the first 2 variates are plotted in Fig. 2.

Separation between all 4 samples is achieved on the 3 variates. The first variate, which accounts for almost 50% of the variance, separates the northern and southern samples widely, with the eastern and central samples lying close together about midway between them. The second and third variates each account for close to a quarter of the variance. The second variate separates the eastern from the 3 coastal samples; the third variate groups the central and eastern samples and separates them progressively more from the northern and southern samples, respectively.

Table 2: Basic statistics of the male and female Western Australian Aboriginal cranial measurements (in mm).

Group and statistic	Max. cran. length	Max. cran. br.	Basi-breg. ht.	Nas.-opis. thion	Bas.-prosth.	Bas.-nasion	Fr.ma. orbi-auric.	Nas.-prosth.	Lambd.-opis. cran.	Lambd.-inion	Inion-opis. thion	Opist.-opis. cran.	Bas.-spheno. bas.
MALE													
N	68	67	64	65	52	58	63	57	69	70	67	66	58
$\overline{X}$	187.23	131.16	131.23	134.77	103.23	101.07	72.86	68.67	25.16	55.69	52.40	79.14	22.95
S.D.	6.27	4.81	5.37	4.59	4.79	4.87	8.50	5.24	9.45	7.22	5.81	7.69	2.50
C.V. (%)	3.35	3.67	4.09	3.41	4.64	4.82	11.67	7.63	37.54	12.97	11.08	9.71	10.90
O.R.	169-202	117-143	121-144	125-148	95-119	91-116	62-133	60-87	9-55	34-73	36-67	60-98	14-28
FEMALE													
N	32	32	32	31	24	30	30	26	33	33	31	31	29
$\overline{X}$	177.03	129.94	127.87	127.35	97.42	96.50	68.67	64.69	28.94	55.15	51.71	76.07	21.35
S.D.	6.73	5.15	6.07	5.70	8.73	8.35	4.64	5.68	9.77	9.72	5.87	7.42	1.45
C.V. (%)	3.80	3.97	4.75	4.47	8.96	8.65	6.76	8.79	33.76	17.63	11.36	9.75	6.77
O.R.	163-191	120-143	115-139	106-141	62-107	76-129	60-79	53-75	10-54	28-77	36-63	59-89	19-25
SEX. DIM.													
‘t’ test*	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	x	xx	xxx	xxx	xxx

* Significance: xxx, P<0.001; xx, P<0.01; x, P<0.05; N.S., not significant

Table 2 (continued)

Group and statistic	Bi-malar br.	Bi-zygom.	Bi-zygion	Bi-auric.	Bi-mast. tips	Bi-infra temp.	Bi-fr.ma. orb.	Bi-ecto chonc.	Bi-coron.	Bi-steph.	Supra orbit. br.	Bi-fronto. temp.	Bi-fronto. sphen.
MALE													
N	55	59	59	62	62	56	60	56	59	62	66	64	51
$\overline{X}$	117.80	92.39	134.76	118.45	97.21	67.25	102.12	99.68	110.58	104.55	109.88	98.34	100.63
S.D.	5.57	5.60	5.03	4.81	4.38	4.07	4.03	3.34	4.48	7.62	4.15	5.68	5.21
C.V. (%)	4.73	6.05	3.73	4.06	4.51	6.06	3.95	3.35	4.06	7.29	3.77	5.78	5.17
O.R.	105-134	80-107	120-150	106-131	88-111	55-77	94-115	93-110	98-124	77-120	100-121	87-115	86-110
FEMALE													
N	23	25	24	31	31	29	26	24	27	27	31	32	27
$\overline{X}$	109.43	87.84	124.29	113.13	94.71	64.41	95.73	94.63	109.59	104.07	102.81	92.25	97.26
S.D.	7.00	5.19	6.49	5.65	5.89	3.68	3.13	2.95	5.23	5.90	4.10	3.01	4.74
C.V. (%)	6.39	5.91	5.22	5.00	6.22	5.71	3.27	3.11	4.77	5.66	3.99	3.26	4.87
O.R.	98-125	80-103	112-140	104-127	86-110	56-72	89-102	89-101	101-119	91-115	95-111	85-97	91-111
SEX. DIM.													
't' test*	xxx	xxx	xxx	xxx	xxx	x	xxx	xxx	xxx	xxx	xxx	xxx	xxx

* Significance: xxx, $P<0.001$; xx, $P<0.01$; x, $P<0.05$; N.S., not significant

Table 2 (continued)

Group and statistic	Bi-aster.	Bi-basi. occip.	Nas.-naso spin.	Nasal br.	Orbit. br.	Orbit. ht.	Inter-orbit. br.	For. magn. length	For. magn. br.	Max.-alv. length	Max.-alv. br.	Palat. ht.	Mast. ht.
MALE													
N	67	58	57	60	58	58	63	58	61	58	58	57	63
$\overline{X}$	107.31	21.43	49.37	27.98	40.43	33.47	21.89	35.09	29.79	60.03	65.62	14.40	30.59
S.D.	4.57	2.10	5.78	2.73	2.79	2.85	2.07	1.99	2.43	3.38	3.57	2.67	3.64
C.V. (%)	4.26	9.66	11.70	9.78	6.90	8.52	9.47	5.66	8.15	5.63	5.45	18.55	11.90
O.R.	97-117	17-32	42-77	23.40-38.50	30.00-44.10	28.50-43.90	18-28	30.90-39.20	24.00-38.50	51-69	57-76	9-21	24-42
FEMALE													
N	33	30	28	29	27	27	32	29	30	28	28	26	31
$\overline{X}$	104.27	19.77	46.14	25.68	39.29	32.33	20.22	33.63	29.81	55.57	62.07	12.27	25.32
S.D.	6.05	2.50	4.84	1.84	3.27	3.19	1.56	2.01	2.72	4.88	3.35	2.13	2.93
C.V. (%)	5.81	12.65	10.50	7.17	8.33	9.85	7.72	5.98	9.13	8.78	5.41	17.34	11.55
O.R.	94-122	11-24	40-59	21.3-29.7	32.20-48.80	25.90-38.20	17-23	29.90-40.20	24.80-39.30	44-63	55-69	9-17	20-33
SEX. DIM.													
‘t’ test*	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx

* Significance: xxx, $P<0.001$; xx, $P<0.01$; x, $P<0.05$; N.S., not significant

Table 2 (continued)

Group and statistic	Nas.-breg. chord	Nas.-breg. arc	Nas.-breg. subt.	Breg.-lambd. chord	Breg.-lambd. arc	Lamb.-opisth. chord	Lamb.-opisth. arc	Bi-por. chord	Bi-por. arc	Por.-breg. chord	Por.-breg. arc
MALE											
N	69	69	67	70	70	68	67	62	62	68	68
$\overline{X}$	112.30	128.33	24.90	115.60	128.39	93.66	115.25	112.58	298.82	125.53	150.77
S.D.	5.14	6.82	2.59	5.14	6.76	5.38	7.05	4.82	11.09	4.98	6.40
C.V. (%)	4.58	5.31	10.40	4.45	5.26	5.74	6.12	4.28	3.71	3.97	4.25
O.R.	99-124	113-145	20-31	104-128	114-144	82-105	100-138	102-128	268-325	113-137	135-168
FEMALE											
N	34	34	34	33	33	31	31	32	31	32	32
$\overline{X}$	106.56	123.27	25.82	109.12	121.76	94.74	116.35	108.81	293.84	121.87	147.59
S.D.	4.52	5.94	2.69	6.73	9.28	5.69	10.04	5.19	9.91	4.48	6.06
C.V. (%)	4.24	4.82	10.42	6.17	7.62	6.01	8.63	4.77	3.37	3.67	4.11
O.R.	95-116	109-138	21-34	97-126	105-147	85-108	99-144	103-124	273-322	113-130	134-163
SEX. DIM.											
't' test*	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx

* Significance: xxx, $P<0.001$; xx, $P<0.01$; x, $P<0.05$; N.S., not significant

Table 3: Basic statistics of the male and female Western Australian Aboriginal cranial indices and ratios.

Group and statistic	Br./ leng.	Ht./ leng.	Ht./ br.	Cran. mod.	Upper facial	Gnath.	Nasal	Orbital	Maxil. alv.	Palatal	For. magn.
MALE											
N	63	61	61	60	53	49	56	57	56	55	56
$\overline{X}$	70.11	70.51	100.74	149.68	50.70	102.21	58.36	82.29	109.37	39.37	85.24
S.D.	2.89	2.81	4.74	4.45	3.17	4.58	8.81	7.67	5.84	3.72	7.59
C.V. (%)	4.13	4.00	4.71	2.97	6.25	4.48	15.00	9.32	5.34	9.44	8.91
O.R.	64.64-76.33	63.78-78.61	90.91-115.75	138.00-158.00	44.53-61.27	90.52-112.12	36.96-87.32	70.31-111.94	96.55-122.13	32.94-51.80	68.62-106.93
FEMALE											
N	29	30	30	29	22	23	27	26	25	26	29
$\overline{X}$	73.52	72.18	97.94	145.35	52.19	101.96	57.24	81.83	113.08	34.36	88.89
S.D.	2.94	3.07	5.80	4.34	5.45	4.30	8.65	6.71	9.81	4.45	9.17
C.V. (%)	4.00	4.25	5.93	2.98	10.44	4.22	15.10	8.19	8.67	12.94	10.31
O.R.	67.76-79.14	66.84-78.31	87.97-109.84	135.67-154.33	43.80-69.68	92.08-110.53	38.10-79.60	68.24-91.60	97.96-140.77	27.13-41.82	69.90-116.62
SEX. DIM.											
't' test*	xxx	xxx	xxx	xxx	xxx	N.S.	xx	N.S.	xxx	xxx	xxx

* Significance: xxx, $P<0.001$; xx, $P<0.01$; x, $P<0.05$; N.S., not significant

Table 3 (continued)

Group and statistic	Nas.-breg. ch/arc	Front. curv.	Breg.-lambda ch/arc	Lamb.-opisth. ch/arc	Bi-porion ch/arc	Nasion-opisth. arc	Nasion-opisth. ch/arc	Por.-breg. ch/arc	Sup.orb. br.-[1] bi. fr.temp.	Sup.orb. br.-[1] bi. fr.sphen.	Malar eversion[2]
MALE											
N	68	65	69	67	61	65	63	67	63	50	52
$\overline{X}$	87.61	22.03	90.11	81.32	38.03	371.12	36.27	83.55	11.46	8.60	15.25
S.D.	2.49	1.75	2.27	3.00	2.91	12.03	1.44	2.26	4.10	5.40	5.28
C.V. (%)	2.84	7.95	2.52	3.68	7.66	3.24	3.97	2.71	35.76	62.82	34.60
O.R.	79.84-97.39	18.58-25.66	79.84-97.39	72.73-88.18	36.62-54.63	338-397	32.72-39.05	75.00-89.86	2-19	0-21	0-23
FEMALE											
N	33	33	32	30	30	30	30	31	30	26	22
$\overline{X}$	86.76	24.52	89.64	81.59	36.93	360.90	35.28	82.84	10.33	6.04	13.27
S.D.	2.98	3.00	3.81	2.74	1.42	14.01	1.69	2.12	4.15	3.40	4.74
C.V. (%)	3.43	12.25	4.25	3.36	3.85	3.88	4.79	2.56	40.21	56.30	35.73
O.R.	81.60-97.70	19.83-36.56	71.43-94.74	73.13-85.86	33.77-40.39	317-393	29.78-38.49	78.23-86.30	2-19	0-16	4-23
SEX. DIM.											
't' test*	xxx	xxx	xxx	xx	xxx	xxx	xxx	xxx	xxx	xxx	xxx

* Significance: xxx, $P<0.001$; xx, $P<0.01$; x, $P<0.05$; N.S., not significant

1 = *minus*

2 = Fronto-malar orbitale — auriculare *minus* bi-malar breadth

Table 4: Basic statistics for the male and female Western Australian Aboriginal mandibular measurements (in mm).

Group and statistic	Mandib. length	Cor. proj. ht.	Cond. proj. ht.	Gonial angle (degrees)	Corp. proj. length	Ram. proj. ht.	Bicon. br.	Bigon. br.	Symph. ht.
MALE									
N	34	34	33	35	34	33	27	33	34
$\overline{X}$	109.15	62.41	54.27	121.60	80.77	59.82	113.85	97.91	33.56
S.D.	5.54	4.31	6.15	7.21	5.97	4.30	5.63	6.23	3.72
C.V. (%)	5.07	6.90	11.32	5.93	7.39	7.20	4.95	6.36	11.08
O.R.	96-125	55-71	43-66	105-136	71-95	51-67	95-122	87-106	26-40
FEMALE									
N	16	15	16	17	17	16	15	17	17
$\overline{X}$	102.94	55.47	47.56	124.59	75.47	53.69	110.73	91.53	29.82
S.D.	6.31	5.94	5.54	6.24	5.36	5.39	5.37	7.71	3.26
C.V. (%)	6.13	10.71	11.64	5.01	7.11	10.04	4.85	8.43	10.95
O.R.	93-117	47-72	41-61	111-135	68-86	45-66	102-120	82-113	23-37
SEX. DIM.									
't' test*	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx

* Significance: xxx, $P<0.001$; xx, $P<0.01$; x, $P<0.05$; N.S., not significant

Table 4 (continued)

Group and statistic	Symph. br.	Corp. ht.	Corp. br.	Ramus ht.	Ram. max. br.	Ram. min. br.	Mand. ant. br.	P_1-M_2 chord	Sigm. notch depth
MALE									
N	36	35	36	34	33	35	34	35	32
$\overline{X}$	14.44	29.51	16.44	64.94	41.82	33.09	46.21	28.26	12.37
S.D.	1.28	5.00	2.12	3.89	3.12	3.72	2.52	2.12	1.68
C.V. (%)	8.83	16.95	12.88	5.99	7.45	11.25	5.45	7.50	13.58
O.R.	13-17	23-49	11-23	57-73	36-46	27-46	40-52	23-33	9-15
FEMALE									
N	17	17	17	16	15	17	17	17	15
$\overline{X}$	13.29	25.77	15.53	60.31	38.47	29.53	44.23	27.12	10.73
S.D.	2.11	2.75	2.15	5.89	3.98	3.81	3.09	2.74	2.01
C.V. (%)	15.91	10.68	13.87	9.76	10.35	12.90	6.99	10.09	18.78
O.R.	10-18	22-32	12-21	52-71	33-47	24-37	41-52	20-32	7-15
SEX. DIM.									
't' test*	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx

* Significance: xxx, $P<0.001$; xx, $P<0.01$; x, $P<0.05$; N.S., not significant

Table 5: Basic statistics (in mm) of four Western Australian male cranial samples, for 15 of the measurements used in the comparison with New South Wales male crania.

Group and statistic	Max. cran. length	Max. cran. br.	Basi breg. ht.	Bas.-prosth.	Bas.-nasion	Bi-zygom.	Supra orbit. br.	Bi-fronto. temp.	Nas.-pros.	Nas.-naso. spin.	Max-alv. br.	Nasal br.	Orb. br.	Orb. ht.	Inter-orbit.
NORTHERN															
N	22	21	20	19	19	19	22	21	20	19	19	20	19	19	20
$\overline{X}$	187.82	130.95	132.45	102.63	102.05	91.11	110.23	98.33	68.00	48.84	65.53	28.06	40.88	34.36	21.60
S.D.	6.37	5.12	5.22	4.89	4.75	5.53	3.99	5.53	5.10	3.48	4.38	3.41	2.92	3.30	1.85
CENTRAL															
N	30	29	28	22	24	27	29	28	25	26	26	26	26	26	28
$\overline{X}$	187.37	131.31	129.61	104.59	100.71	93.11	109.62	97.96	70.40	51.15	66.23	28.31	40.09	33.66	21.71
S.D.	7.41	4.98	5.38	4.63	5.24	6.06	4.72	6.09	5.74	7.40	3.22	2.66	3.11	2.73	1.94
SOUTHERN															
N	10	11	10	5	9	7	9	9	6	6	7	8	7	7	9
$\overline{X}$	186.30	132.82	133.50	102.60	102.56	93.14	109.22	101.11	66.33	47.33	65.57	26.70	39.84	31.16	22.78
S.D.	3.71	3.31	6.01	3.85	3.81	5.31	3.71	5.71	2.07	2.58	2.76	1.36	1.63	1.31	2.49
EASTERN															
N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
$\overline{X}$	186.00	128.17	131.00	100.67	97.17	92.33	110.83	96.00	66.00	45.33	63.33	27.93	41.20	32.57	22.33
S.D.	2.76	4.79	2.61	5.32	3.54	4.27	2.64	3.35	3.79	2.81	2.73	1.73	1.97	1.63	2.81

Table 6: Basic statistics (in mm) of four Western Australian male cranial samples, for the most highly weighted variables from the cranial canonical analyses, plus 4 indices discussed in the text.

Group and statistic	Breg.-lambd. chord	Breg.-lambd. arc	Porion-breg. chord	Porion-breg. arc	Lambd.-opisth. chord	Lambd.-opisth. arc	Lambd.-inion	Inion-opisth.	Bi-fronto sphen.	Bi-malar br.	Bi-coron.	Bi-steph.	Bi-zygion
NORTHERN													
N	22	22	21	21	22	22	22	21	19	18	20	20	19
$\overline{X}$	115.64	128.32	126.67	151.24	93.50	115.64	55.23	52.67	101.00	118.11	110.55	104.05	135.32
S.D.	5.69	7.75	5.76	7.44	5.91	7.58	7.89	5.50	4.88	5.90	4.06	8.19	5.73
CENTRAL													
N	31	31	31	31	29	28	31	29	21	25	25	26	26
$\overline{X}$	115.27	127.74	124.90	150.29	93.69	115.57	57.13	51.35	102.29	118.12	111.36	104.50	135.42
S.D.	4.75	5.94	4.92	5.81	5.01	7.61	5.89	5.81	4.76	5.56	5.31	7.88	5.03
SOUTHERN													
N	11	11	10	10	11	11	11	11	6	7	9	11	8
$\overline{X}$	114.82	129.00	125.70	153.10	96.09	116.55	56.00	53.18	98.33	114.57	110.67	105.73	132.87
S.D.	5.46	7.95	4.81	7.08	4.93	4.30	6.77	5.95	3.98	3.87	2.50	7.98	3.68
EASTERN													
N	6	6	6	6	6	6	6	6	5	5	5	5	6
$\overline{X}$	118.83	130.83	124.50	147.67	89.67	110.00	49.38	55.17	95.00	119.60	106.60	104.20	132.67
S.D.	4.45	5.35	2.07	3.27	4.41	5.21	9.81	6.85	6.00	6.27	2.88	3.83	3.93

Table 6 (continued)

Group and statistic	Nas.-breg. chord	Nas.-breg. arc	Bi-auric.	Bi-porion chord	Bi-porion arc	Nas.-breg. subt.	Mast. ht.	Nas.-opis. thion.	Bi-basi. occip.	Breg.-lambd. ch./arc	Porion-breg. ch./arc	Lambd.-opisth. ch./arc	Nas.-breg. ch./arc
NORTHERN													
N	21	21	19	19	19	21	19	21	19	22	21	22	21
$\overline{X}$	113.33	128.67	117.63	113.11	299.26	24.33	29.26	136.00	21.21	90.12	83.83	80.53	87.71
S.D.	5.57	7.25	5.87	5.89	12.19	2.73	2.64	5.59	1.62	1.94	2.56	2.89	2.74
CENTRAL													
N	31	31	28	29	29	29	29	28	25	30	30	28	30
$\overline{X}$	112.13	128.00	119.00	112.24	298.38	24.96	31.72	134.43	21.68	90.16	83.34	81.44	87.76
S.D.	5.11	7.13	4.68	4.82	10.68	2.60	3.85	4.18	2.67	2.22	1.99	3.05	1.52
SOUTHERN													
N	11	11	9	8	8	11	10	11	8	11	10	11	11
$\overline{X}$	112.82	128.82	118.33	111.50	303.37	24.82	30.30	134.73	21.63	89.53	83.14	82.47	88.48
S.D.	3.34	6.65	4.18	3.51	12.83	2.32	4.64	4.05	1.51	3.33	2.58	3.61	3.34
EASTERN													
N	6	6	6	6	6	6	5	6	6	6	6	6	6
$\overline{X}$	108.67	128.00	118.67	114.00	293.50	26.67	29.60	132.33	20.83	90.85	84.34	81.52	84.88
S.D.	5.92	5.21	2.73	2.37	4.42	2.25	1.52	3.20	0.98	1.53	2.12	1.17	2.53

Table 7: Canonical variate means for four Western Australian male samples, using 50 cranial variables.

Samples	Canonical Variate Means		
	C.V. 1	C.V. 2	C.V. 3
Northern	4.747	11.922	10.114
Central	-0.086	13.789	13.781
Southern	-5.470	12.905	7.349
Eastern	-1.009	5.430	13.048
Canonical root:	11.983	7.131	5.564
% of variance accounted for:	48.6	28.9	22.5

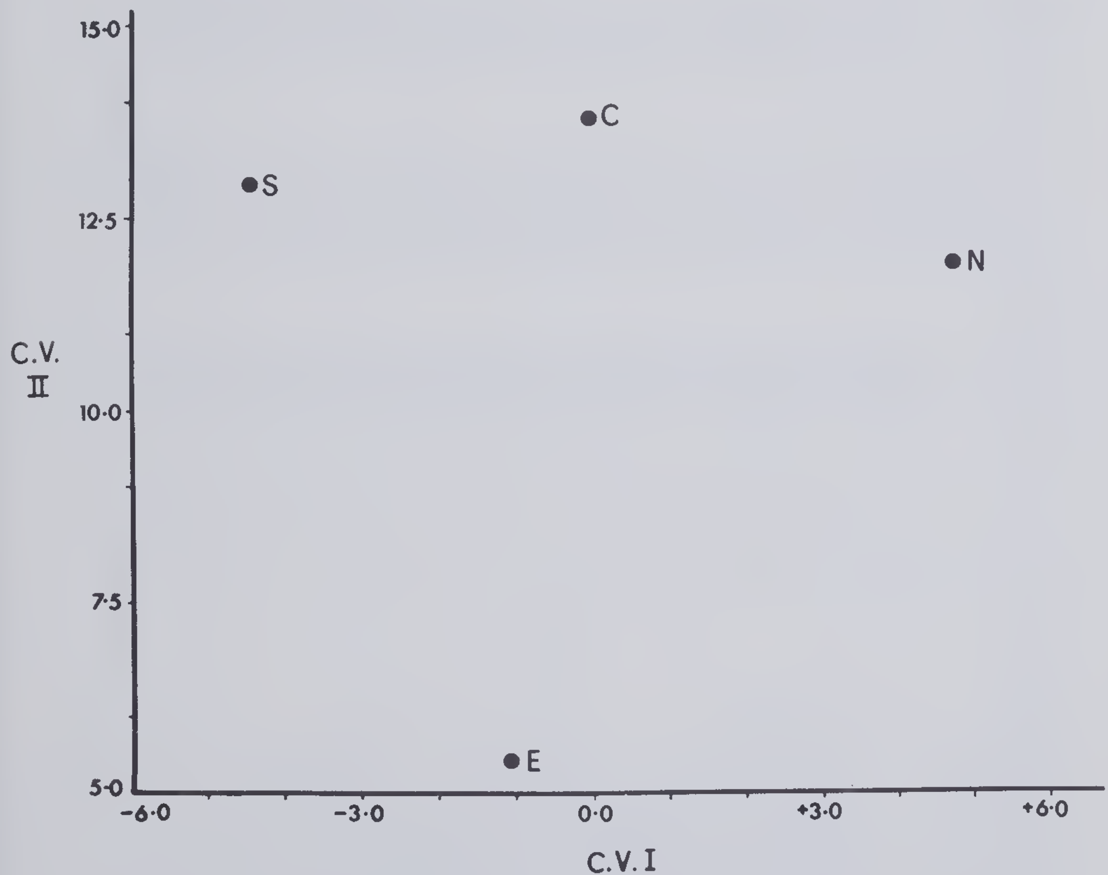

Fig. 2: Plot of canonical variate 1 means against canonical variate 2 means for the 4 Western Australian male cranial samples, using 50 variables.

Table 8: Canonical variate analysis of four Western Australian male cranial samples, using 50 cranial variables.

	Unweighted			Weighted		
	Variate I	Variate II	Variate III	Variate I	Variate II	Variate III
Maximum cranial length	-0.066	0.113	0.035	-0.412	0.698	0.220
Maximum cranial breadth	-0.182	-0.111	-0.583	-0.902	-0.549	-2.896
Basi-bregmatic height	0.127	-0.589	-0.131	0.632	-2.788	-0.652
Nasion-opisthion	0.326	-0.435	-0.454	1.446	-1.923	-2.012
Basion-prosthion	-0.531	0.093	0.201	-2.549	0.445	0.966
Basion-nasion	-0.087	0.454	-0.087	-0.041	2.143	-0.411
Fronto-malar orbitale auriculare	-0.176	-0.176	0.145	-0.660	-0.627	0.517
Nasion-prosthion	0.297	-0.198	0.057	1.459	-0.974	0.281
Lambda-opisthocranion	0.034	-0.069	-0.088	0.360	-0.620	-0.254
Lambda-inion	-0.389	-0.235	-0.082	-2.927	-1.768	-0.616
Inion-opisthion	-0.446	-0.082	0.015	-2.799	-0.514	0.097
Opisthion-opisthocranion	-0.006	0.006	0.039	-0.881	0.048	0.287
Basion-sphenobasion	-0.240	0.240	0.224	-0.711	0.640	0.597
Bi-malar breadth	0.034	-0.034	-0.075	2.536	-0.190	-0.423
Bi-zygomaxillare	-0.038	-0.238	-0.213	-0.215	-1.329	-1.181
Bi-zygion	-0.402	0.405	0.257	-1.991	2.005	1.274

Table 8 (continued)

	Unweighted			Weighted		
	Variate I	Variate II	Variate III	Variate I	Variate II	Variate III
Bi-auriculare	0.399	-0.664	-0.154	0.198	-3.293	-0.763
Bi-mastoid	0.175	0.175	-0.190	0.388	0.786	-0.854
Bi-infratemporale	0.007	0.007	0.309	0.897	0.031	1.292
Bi-frontomalar orbitale	-0.222	-0.222	-0.310	-0.087	-0.961	-1.345
Bi-ectoconchion	-0.265	0.190	0.136	-0.919	0.659	0.472
Bi-coronalia	-0.258	0.258	-0.340	-1.224	1.098	-1.445
Bi-stephanion	-0.007	-0.007	0.246	-1.239	-0.052	1.626
Supra-orbital breadth	-0.130	-0.289	0.480	-0.566	-1.261	2.093
Bi-frontotemporale	0.312	-0.258	0.099	1.844	-1.527	0.589
Bi-frontosphenoidale	0.623	0.060	0.284	2.949	0.285	1.345
Bi-asterion	-0.015	0.089	0.043	-0.067	0.396	0.188
Bi-basioccipital	0.371	0.371	-0.731	0.779	0.837	-1.651
Nasion-nasospinale	-0.127	0.025	0.210	-0.718	0.143	1.185
Nasal breadth	0.313	-0.126	-0.008	0.897	-0.362	-0.024
Orbital breadth	-0.309	0.087	-0.180	-0.093	0.262	-0.543
Orbital height	0.466	0.015	0.172	1.372	0.046	0.507
Interorbital breadth	0.423	0.099	0.358	0.905	0.213	0.766
Foramen magnum length	-0.089	-0.119	0.527	-0.183	-0.246	1.091

Table 8 (continued)

	Unweighted			Weighted		
	Variate I	Variate II	Variate III	Variate I	Variate II	Variate III
Foramen magnum breadth	-0.314	0.352	0.399	-0.756	0.848	0.962
Maxillo-alveolar length	0.284	0.183	0.444	0.777	0.502	1.215
Maxillo-alveolar breadth	-0.115	0.120	-0.350	-0.432	0.452	-1.311
Palatal height	0.367	-0.258	0.254	0.959	-0.673	0.664
Mastoid height	-0.557	0.557	0.429	-1.713	1.852	1.427
Nasion-bregma chord	-0.018	0.371	0.892	-0.092	1.849	0.444
Nasion-bregma arc	0.139	-0.287	0.102	0.959	-1.983	0.702
Nasion-bregma subtense	-0.405	0.465	0.161	-1.024	1.350	0.467
Bregma-lambda chord	-0.473	-0.097	-0.313	-2.506	-0.515	-1.659
Bregma-lambda arc	0.039	-0.210	0.225	2.820	-1.498	1.602
Lambda-opisthion chord	-0.183	0.311	-0.038	-0.921	1.564	-0.191
Lambda-opisthion arc	0.699	0.014	-0.034	4.963	0.097	-0.238
Bi-porion chord	0.084	0.257	0.273	0.360	1.096	1.164
Bi-porion arc	0.024	0.018	-0.145	0.262	0.192	-1.570
Porion-bregma chord	0.320	0.210	-0.005	1.569	1.028	-0.027
Porion-bregma arc	-0.233	0.310	0.150	-1.534	2.235	0.988

The unweighted and weighted coefficients for the 3 variates are listed in Table 8. For the 50 variables studied there are over 20 positive and over 20 negative coefficients in each of the 3 variates. From this one would conclude that, in each case, shape rather than size differences are the most significant features in the discrimination.

For the first canonical variate (Table 8) the weighted coefficients imply that major contrasts exist between the positively weighted lambda-opisthion arc (+ 4.963), bi-frontosphenoidale (+ 2.949), bregma-lambda arc (+ 2.820), bi-malar breadth (+ 2.536) and bi-frontotemporale (+ 1.844) and the negatively weighted lambda-inion (- 2.927), inion-opisthion (- 2.799), basion-prosthion (- 2.549), bregma-lambda chord (- 2.506) and bi-zygion (- 1.991). From these coefficients the major contrasts appear to be in the posterior part of the cranial vault and, to a lesser extent, in variations between cranial breadth measurements.

The canonical variate and univariate data, viewed together, reveal interesting variations in the parietal bone. The first canonical variate high values and opposite signs of the bregma-lambda chord (+ 2.820) and arc (- 2.506) reflect significant antero-posterior curvature differences between this bone in the 4 samples. Referring to the univariate statistics in Table 6, it can be seen that the southern population has a relatively long arc and short chord measurement, making the parietal bone more rounded; the eastern sample has the longest arc and chord measurements, but the relatively longer chord measurement results in a less rounded parietal. Further, the coefficients of the porion-bregma chord (+ 1.569) and arc (- 1.534) indicate important sample differences in the mesio-lateral curvatures of the parietal bone. The univariate statistics (Table 6) show the southern sample to have the relatively longest arc measurement, with the chord/arc index increasing progressively from southern to central to northern to eastern. Thus, the southern sample has an overall antero-posteriorly and mesio-laterally rounder parietal bone, whereas in the eastern sample it is relatively flatter in both directions; the northern and central sample shapes are intermediate.

The contrasting on the first canonical variate (Table 8) between lambda-opisthion chord (+ 4.960) and lambda-opisthion arc (- 0.921) suggests both size and shape variation in the occipital bone. On univariate statistics (Table 6) the southern sample has the absolutely longest arc and chord measurements, and the eastern the lowest for both dimensions. Relatively however (lambda-opisthion chord/arc), the occipital in the southern sample turns out to be considerably less rounded than the eastern sample; the northern and central samples are more rounded than even the eastern sample.

The large first canonical variate coefficients (Table 8) for lambda-inion (- 2.927) and inion-opisthion (- 2.799) also indicate occipital bone variations. From the univariate statistics in Table 6 it can be seen that these measurements show considerable absolute and relative differences and indicate marked variations in the degree of development of inion, or of its location relative to lambda and opisthion.

Several breadth measurements indicate cranial shape variations on the first canonical variate (Table 8). Three positive breadth measurements (bi-frontosphenoidale, + 2.949; bi-malar breadth, + 2.536; bi-frontotemporale, + 1.844) contrast with three negative breadth measurements (bi-zygion, - 1.991; bi-stephanion, - 1.239; bi-coronalia, - 1.224). From the univariate results (Tables 5 and 6) the northern and central crania have large bi-frontosphenoidale breadths, while those from the south and east have small bi-zygion breadths; the southern population has a relatively narrow bi-malar breadth, which contrasts to its broad bi-frontotemporale measurement.

One other readily apparent contrast from the weighted coefficients of canonical variate one (Table 8) is between nasion-prosthion (+ 1.459) and basion-prosthion (- 2.549). From the appropriate univariate data (Table 5) the southern population is the most divergent sample, having a short upper facial height (nasion-prosthion) and a long basion-prosthion measurement, probably implying a more prognathic face. The eastern sample, with small dimensions for both measurements, shows a similar metrical relationship to the southern sample; the northern and central samples have relatively long upper facial heights compared with their basion-prosthion dimensions.

On the second canonical variate mean scores (Table 7), the isolation of the eastern population is mainly due to differences (Table 8) between the positively weighted coefficients, porion-bregma arc (+ 2.235), basion-nasion (+ 2.143), bi-zygion (+ 2.005), mastoid height (+ 1.852), nasion-bregma chord (+ 1.849), and the negatively weighted coefficients, bi-auriculare (- 3.293), basi-bregmatic height (- 2.788), nasion-bregma arc (- 1.983) and nasion-opisthion (- 1.923). The main isolating features appear to be in breadth-height relationships, and in the shape of the frontal bone.

From the univariate results (Table 5) the eastern population has the shortest measurements (often considerably so) for all of the highly weighted second variate positive values. The eastern population is also separated because of frontal bone chord-arc differences; from the univariate results (Table 6), it is apparent that, relative to the nasion-bregma chord measurement, the eastern population has a long arc measurement. The increased arc is also supported by the greater nasion-bregma subtense measurement of the eastern population. The above differences show that the eastern population is distinct from the more nearly similar northern, central and southern populations in having a number of considerably smaller dimensions and also in its antero-posteriorly being more rounded, i.e. fuller frontal bone. Breadth dimensions also play a significant part in the discrimination on this second canonical variate. Thus, bi-frontotemporale (- 1.527) is by far the smallest in the eastern sample and bi-auriculare (- 3.293) appears to be important in the separation of northern and central from the other 2 samples and also from each other.

In the third canonical variate the highest positively weighted coefficients (Table 8) are supra-orbital breadth (+ 2.093), bi-stephanion (+ 1.626), bregma-lambda arc (+ 1.602), mastoid height (+ 1.427) and bi-fronto-sphenoidale (+ 1.345). The most highly weighted negative coefficients are for maximum cranial breadth (- 2.896), nasion-opisthion (- 2.012), bregma-lambda chord (- 1.659), bi-basioccipital (- 1.651), bi-porion arc (- 1.570) and maxillo-alveolar breadth (- 1.311). The separation achieved on the third canonical variate is principally of the southern samples from the central and eastern samples, with the northern samples intermediate. These coefficients re-emphasize the variation of the sample from the south in respect to parietal bone shape and also certain breadth measurement variations.

From the univariate results (Tables 5 and 6), in addition to the bregma-lambda chord/arc relationships already discussed, it can be seen that the southern sample has the largest measurements for bi-stephanion, bi-fronto-temporale and bi-porion arc, and the shortest measurement for supra-orbital breadth. Except for the parietal bone differences it would seem that this third canonical variate mainly stresses size differences.

Because of the limited findings for the male 4 sample cranial subsets, cranial indices and mandibles, the male 7 sample analysis, and the female 4 sample analysis no detailed tables of results have been included. However, the salient points emerging from those analyses will be briefly outlined in (b) to (f) below.

(b) Cranial subsets, 4 male Western Australian samples

Using the 17 facial variables only it can be seen from the small canonical roots that there is considerable reduction of the between relative to within group variance. Separation is poor on all 3 variates but the first does separate the southern from the other 3 samples. In the 17 variable cranial vault analysis separation is improved and is, in fact, complete on the 3 variates.

Although separation on this analysis is different to that on the whole cranium, this subset probably includes the most important variables involved in separating the samples. On the 8 cranial base dimensions separation is very poor, although on the first variate the central-southern are separated from the northern-eastern samples.

(c) Cranial indices, 19 variables, 4 male Western Australian samples

The cranial indices should reflect cranial shape differences well but do not result in good separation by canonical analysis. Samples tend to be paired in the variates, central-eastern in the first, central-southern in the second, and northern-central and also southern-eastern in the third variate.

(d) Mandibular measurements, 18 variables, 4 male Western Australian samples

The mandibular variables, on the first two canonical variates, give a similar picture of separation to that found on the whole cranium analysis. However, two of the numbers of mandibular specimens available were very small (northern — 12, central — 16, southern — 6, eastern — 2) and hence the results may not be reliable.

(e) Whole cranium, 50 variables, 7 male Western Australian samples

The canonical analysis using 7 samples for the northern-central combined area was based on rather small samples (4-8) and results are thus of doubtful validity. There is a clustering of 3 or 4 of the sample means on each variate but nevertheless a suggestion of a fair amount of between sample variation.

(f) Whole cranium, 15 variables, 4 female Western Australian samples

A single analysis was made of the 4 female samples but using only 15 of the cranial variables used in the coastal New South Wales study (Freedman, 1964). Separation was obtained on the 3 variates. The first puts the southern and eastern together between the northern and central samples; the second separates the southern from the other 3 samples; the third separates the eastern from the remaining 3 samples. Numbers in these 4 samples are very small (northern, 6; central, 5; southern, 11; eastern 3).

(g) Whole cranium, 15 variables, 4 male Western Australian and 3 coastal New South Wales samples

The variables utilised in this analysis are those used by Freedman (1964) except that, because of missing measurements, maxillo-alveolar length and bi-zygion breadth were omitted and interorbital breadth included. (For coastal New South Wales the basic univariate statistics for interorbital breadth in the 3 samples are: northern — N = 14, $\overline{X}$ = 19.79 mm, S.D. = 2.15 mm; central — N = 27, $\overline{X}$ = 18.93 mm, S.D. = 2.33; southern — N = 10, $\overline{X}$ = 19.00 mm; S.D. = 2.62 mm).

On the first canonical variate, which accounts for over 55% of the variance (Table 9, Fig. 3), the groups of samples from the 2 States are clearly separated. The second variate accounts for 19% of the variance; it spreads the 4 Western Australian samples, and separates the southern from the northern-central New South Wales samples. The third variate separates the southern from the other 3 Western Australian samples, and the central from the northern-southern samples from New South Wales; it accounts for only 9% of the variance. In each of the first 3 variates there are approximately similar numbers of positively and negatively weighted measurements.

On the first canonical variate the main positively weighted coefficients (Table 10) are basi-bregmatic height (+ 0.545), maxillo-alveolar breadth (+ 0.517) and maximum cranial breadth (+ 0.403), and the main negatively weighted coefficients are interorbital breadth (– 0.778), maximum cranial length (– 0.258) and nasion-nasospinale (– 0.255). The contrasting of maxillo-alveolar breadth (+ 0.517) and maximum cranial breadth (+ 0.403) with interorbital breadth (– 0.778) suggests that relative changes in breadth measurements are the most important in this variate.

From the univariate results (Freedman, 1964; and Tables 5 and 6), it can be seen that, for the 3 most heavily positively weighted measurements, the Western Australian samples almost all have smaller dimensions than those for the New South Wales samples; the only exceptions are the southern sample for basi-bregmatic height and maximum cranial breadth. For the only heavily negatively weighted measurement (interorbital breadth) the New South Wales mean sample measurements are all smaller than those from Western Australia. The contrasting of these breadth dimensions must mainly be responsible for the clear separation achieved. On these dimensions, and on the variate as a whole (Table 9, Fig. 3), the northern New South Wales sample most resembles the Western Australian samples; of the Western Australian samples, the eastern sample diverges most and in the opposite direction to the New South Wales samples.

The second canonical variate weighted coefficients (Table 10) highlight the positive coefficients of basi-bregmatic height (+ 0.681), interorbital breadth (+ 0.341), orbital breadth (+ 0.321) and nasion-prosthion (+ 0.319), and the negative coefficients of nasion-nasospinale (– 0.985) and basion-prosthion (– 0.588). In this variate height dimensions are mainly stressed, basi-bregmatic height getting a large positive coefficient.

The relationship between nasion-prosthion and nasion-nasospinale is especially interesting in this variate. The univariate statistics of the Western Australian samples in Table 5 show considerable variation for the nasion-nasospinale dimension and, when looked at relative to the nasion-prosthion measurement, it widely separates the eastern and central samples and locates the northern and southern in between, as does the variate as a whole. This is the main effect of this variate. The univariate mean values for basi-bregmatic height (Freedman, 1964) spread the New South Wales samples clinally, increasing from north to south, while the basion-prosthion values increase clinally in the opposite direction.

For the third canonical variate, the highest positively weighted coefficients from Table 10 are for orbital height (+ 0.639), nasal breadth (+ 0.581) and bi-zygomaxillare (+ 0.372). The main negative coefficients are bi-fronto-temporale (– 0.433) and nasion-nasospinale (– 0.362). The positive co-efficients for the orbital height and nasal breadth reflect the small mean univariate measurements for these variables in the southern Western Australian sample (Table 5). The major new contrast which emerges is between bi-zygomaxillare and bi-frontotemporale. From the univariate statistics (Table 5) the southern Western Australian sample has a broad bi-fronto-temporale measurement relative to its bi-zygomaxillare breadth.

(B) Generalized distance analyses

(a) Western Australian samples

Generalized distance analyses were performed on all of the samples used for canonical analyses, except the two 50 variable analyses (male whole cranium, 4 sample and male whole cranium, 7 sample). As for the equivalent canonical analyses no tables of results are included for the generalized distance analyses.

From the male face and vault subset distance analyses the only consistent results are that, in each case, the distance separation between the northern and central samples is the smallest (2.16 and 1.96, respectively) and the D^2 value for the southern-eastern comparison the largest (12.14 and 13.07, respectively); the male cranial base subset analysis gives the smallest D^2 values (0.32 — 1.46) and poor discrimination. The male cranial indices analysis again results in the northern-central D^2 value being the lowest (3.67) and the southern-eastern the highest (13.01). The distances from north to central (3.67), north to south (5.60) and north to east (6.12) increase progressively. The male mandibular generalized distances are by far the largest. The northern-central figure is again the lowest (14.97) but, in this case, the central-eastern value (69.24) is slightly higher than that for the southern-eastern comparison (65.73). The female cranial distance analysis results in large distances between the samples but makes the northern-central value the largest (41.58) and the southern-eastern figure the smallest (13.91).

(b) Western Australian and New South Wales samples

A number of interesting results emerge from this last generalized distance analysis (Table 11). In each State there is a progressively increasing D^2 distance down the coast of the central and southern samples from the northern sample. Comparing the samples from the 2 States, the 2 northern samples are very similar and the D^2 distances between the equivalent parts of each State increase progressively in the central and southern comparisons. The Western Australian eastern sample is well separated from all of the other samples from the 2 States; the largest D^2 values found are between that sample (eastern Western Australia) and the 3 New South Wales samples, and the values are progressively greater from north to south.

Table 9: Canonical variate means for four Western Australian and three New South Wales male samples, using 15 cranial variables.

Sample	Canonical Variate Means		
	C.V. 1	C.V. 2	C.V. 3
WESTERN AUSTRALIA			
Northern	17.587	3.309	3.976
Central	17.413	2.173	3.875
Southern	17.791	3.798	2.397
Eastern	16.849	4.651	4.144
NEW SOUTH WALES			
Northern	18.686	2.946	4.435
Central	19.730	2.850	3.628
Southern	19.858	3.765	4.210
Canonical root:	1.282	0.440	0.215
% variation accounted for:	55.7	19.1	9.3

Table 10: Canonical variate analysis of four Western Australian, and three New South Wales* male cranial samples, using 15 cranial variables.

	Unweighted			Weighted		
	Variate I	Variate II	Variate III	Variate I	Variate II	Variate III
Maximum cranial length	-0.039	0.035	0.022	-0.258	0.230	0.145
Maximum cranial breadth	0.087	-0.058	-0.061	0.403	-0.268	-0.285
Basi-bregmatic height	0.116	0.145	-0.031	0.545	0.681	-0.148
Basion-prosthion	-0.004	-0.135	-0.016	-0.017	-0.588	-0.068
Basion-nasion	0.027	-0.019	-0.021	0.113	-0.081	-0.091
Bi-zygomaxillare	0.012	0.044	0.073	0.062	0.227	0.372
Supra-orbital breadth	0.019	0.028	-0.007	0.083	0.119	-0.031
Bi-frontotemporale	-0.045	-0.050	-0.082	-0.240	-0.268	-0.433
Nasion-prosthion	0.002	0.075	0.066	0.007	0.319	0.279
Nasion-nasospinale	-0.057	-0.222	-0.081	-0.255	-0.985	-0.362
Maxillo-alveolar breadth	0.155	-0.033	-0.007	0.517	-0.111	-0.023
Nasal breadth	-0.082	-0.119	0.238	-0.199	-0.289	0.581
Orbit breadth	-0.010	0.135	0.104	-0.024	0.321	0.248
Orbit height	0.005	0.027	0.257	0.013	0.069	0.639
Interorbital breadth	-0.360	0.158	-0.086	-0.778	0.341	-0.186

* Data from Freedman (1964)

Table 11: Generalized distance analysis of the four Western Australian and three New South Wales male samples, using 15 cranial measurements.

	GENERALIZED DISTANCE (D^2)						
	WESTERN AUSTRALIA				NEW SOUTH WALES		
	Northern	Central	Southern	Eastern	Northern	Central	Southern
WESTERN AUSTRALIA							
Northern	—	2.33	3.72	5.17	2.30	5.60	6.67
Central		—	5.26	7.79	2.88	6.32	8.99
Southern			—	7.11	5.98	7.12	7.79
Eastern				—	7.81	12.53	12.83
NEW SOUTH WALES							
Northern					—	2.10	3.01
Central						—	2.59
Southern							—

Table 12: Mean scores for each of the 7 sexing characters recorded for the male and female Western Australian crania. Larnach and Freedman's (1964) scores for New South Wales coastal crania are listed in brackets.

	Glabella	Super-ciliary ridges	Zygo-matic trigone	Malar tuber-osity	Mastoid size	Palatal size	Occipital markings	Total mean
Male:	2.30	2.27	2.17	1.82	2.96	2.27	1.73	15.50
	(2.26)	(2.41)	(2.57)	(2.35)	(2.28)	(2.69)	(2.55)	(17.11)
Female:	1.37	1.29	1.36	1.23	2.11	1.63	1.18	10.17
	(1.08)	(1.03)	(1.31)	(1.00)	(1.03)	(1.55)	(1.05)	(8.05)
Difference:	0.93	0.98	0.81	0.59	0.85	0.64	0.55	5.33
	(1.14)	(1.38)	(1.26)	(1.35)	(1.25)	(1.14)	(1.50)	(9.06)

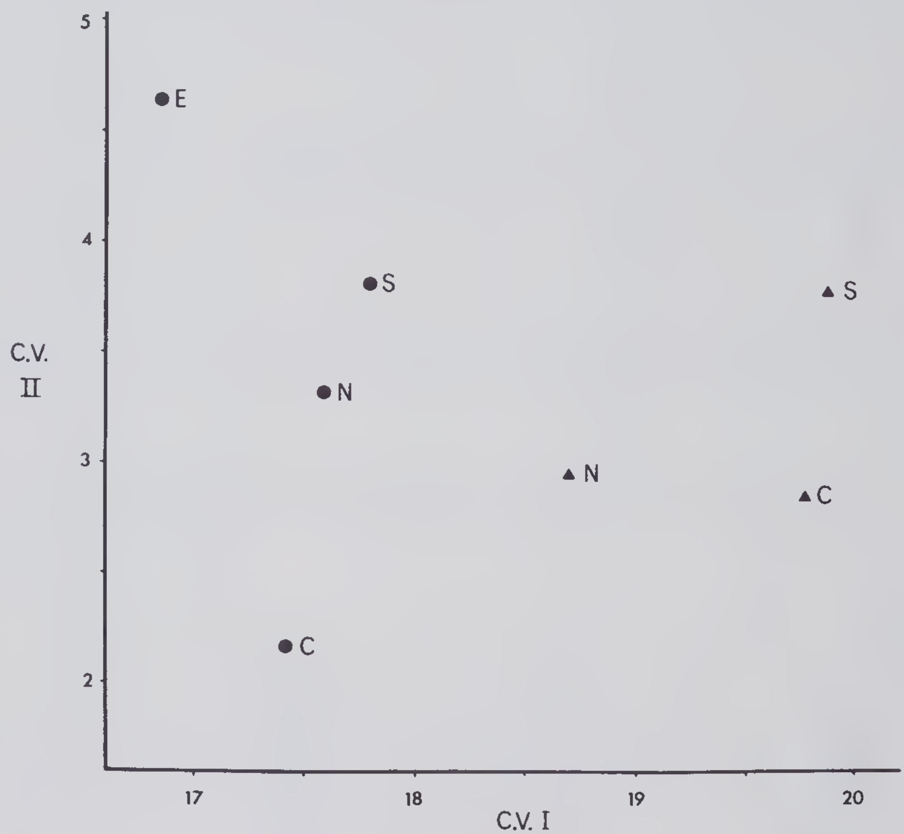

Fig. 3: Plot of canonical variate 1 means against canonical variate 2 means for the 4 Western Australian and 3 coastal New South Wales male cranial samples, using 15 variables.

DISCUSSION

From the checks performed, it would seem that the sexing procedure used (Larnach & Freedman, 1964) has differentiated male and female crania with a high degree of accuracy. (Each character is rated on a scale 1 to 3 with males tending to have the high values.) It is of interest that the mean scores obtained for the 7 sexing characters in the male Western Australian cranial samples were smaller than the equivalents from New South Wales in all but 2 instances (Table 12). The male mean score most significantly greater in the New South Wales sample was occipital markings where the difference was 0.82; 3 other differences (malar tuberosity, palatal size and zygomatic trigone) were larger in that sample in the range 0.40-0.53. Of the sexing features larger in the Western Australian sample, only the mastoid size difference was markedly bigger (0.68). On the other hand, in the female mean values the Western Australian scores were greater in each instance but none by a very large amount (less than 0.24).

The total mean difference between the 2 sexes was markedly less in the Western Australian sample (5.33) as compared with that for New South Wales (9.06). The greatest mean size differences between the sexes for the 2 samples were in the occipital markings (0.95) and in the size of the malar tuberosity (0.76). To some extent the variations between the samples may reflect observer differences, but 2 of the features were quantitative, and casts of the limits of the middle value (2) for each of the other features were used in making the assessments. It would therefore seem that there may well be real differences between the 2 samples in the amount of sexual dimorphism.

On univariate analysis the Western Australian crania of the 2 sexes were found to be substantially different (Tables 2-4) and hence were studied separately. Comparing the male and female mean values with those of the New South Wales series (Freedman, 1964) showed that, overall, the latter crania were larger. Thus, the male Western Australian crania were smaller, on average, for 11/16 features for which comparable data were available. The instances where the New South Wales mean differences were considerably larger were: basi-bregmatic height (3.22 mm), maxillo-alveolar breadth (2.57 mm) and maximum cranial breadth (2.04 mm). The mean measurements on which the Western Australian male mean values were considerably greater were: bi-frontotemporale (1.28 mm), orbital breadth (1.10 mm) and nasal breadth (0.55 mm). For the female mean dimensions, the New South Wales sample was larger for 12/16 features. They were considerably larger in maxillo-alveolar length (2.56 mm), basi-bregmatic height (2.24 mm), basion-prosthion (2.14 mm) and maximum cranial length (1.88 mm). The only measurements for which the Western Australian female sample mean was considerably larger was orbital breadth (1.84 mm).

It is interesting to note that for males, both on sexing characters and univariate mean values, the New South Wales sample figures were mostly greater than those for Western Australia. On the other hand, for females, the sexing character values for Western Australia were all greater than those for New South Wales but, for the univariate mean values, the New South Wales figures were mostly larger.

Comparisons were also made between the cranial univariate statistics obtained in the present study with those of 3 earlier studies (Morant, 1927; Hrdlicka, 1928; Wagner, 1937). Only mean values for small male samples were reported in each of these studies and hence neither 't' tests nor more complex analyses could be used for making comparisons. Only 6 measurements were common to all 4 studies, a further 5 to 3, and 8 to only the present and one other study.

Considering the 3 primary cranial measurements first, the mean maximum cranial lengths reported by Morant and Hrdlicka were close to that obtained in the present study (187.23 mm); however, Wagner recorded a considerably lower mean value (184.9 mm). For basi-bregmatic height and maximum cranial breadth Hrdlicka and Morant recorded larger mean values and Wagner smaller values. Perhaps more importantly, however, there are variations in relative size between these two measurements in the four studies. Thus, in the present study the 2 mean dimensions were very close, with height just slightly greater (0.08 mm), whereas Hrdlicka and Wagner recorded breadth greater than height (132.5 mm to 131.9 mm and 130.6 mm to 129.4 mm, respectively) and Morant records height (132.6 mm) greater than breadth (130.8 mm). These differences affect all three primary cranial indices (breadth/length, height/length and height/breadth).

Of the remaining dimensions for which mean values are available for all 4 studies, nasal breadth is relatively uniform for the 3 earlier studies (26.1-26.8 mm) but the figure recorded in this study for Western Australia is rather larger (27.98 mm). Of those for which 2 other samples have comparable dimensions, bi-zygion is 1.66 mm greater in the Western Australian sample than in the largest mean value of the other available dimensions and, for basion-prosthion, Hrdlicka's mean is almost 2 mm greater than that of Wagner and the present study. Where comparisons of the present study with single other studies are involved, variations of 1-2 mm occur. Some caution is clearly necessary in assessing the significance of such comparisons as these because of possible variations in technique. This is almost certainly the case for nasion-prosthion and orbital breadth where mean dimensions are available for 3 studies and variation in the former is 64.9-71.1 mm and in the latter from 39.9 to 44.3 mm. Further, in making comparisons between the Western Australian and other samples it has had to be assumed that prosthion and alveolar point, basion and endobasion, and nariale and naso-spinale are similar enough for comparisons to be made. The necessity for standardisation and a basic set of measurements and non-metrical observations on crania from particular areas is urgently required.

The canonical variate analysis of the Western Australian male cranial material has revealed considerable variation between samples from the northern, central, southern, and eastern subdivisions. Using the whole cranium, separation of the 4 samples is achieved on the 3 variates, and subset analysis confirms that the main discriminating features are in the calvarial vault, rather than the face or base. Canonical analysis of the cranial indices was disappointing, possibly because the association of features in the indices may not be the best ones for reflecting shape differences in this material. Small numbers made the male mandibular and female cranial canonical analyses unreliable, although the former gave similar results to the male, whole cranium analysis. The 7 sample northern-central analysis also suffered from the smallness of the samples but the results did appear to reinforce the general variability of the crania from Western Australia.

The main inter-relationships emerging from the 50 variable, 4 Western Australian sample canonical analysis (Table 7) were those of a north to south coastal cline, with the eastern sample being most similar to the central on the first variate but well separated from all 3 coastal samples on the second. The univariate statistics were used to analyse the sample differences in the highly weighted features of the canonical variates.

In this canonical analysis breadth measurements were found to account for a considerable amount of the variation — a result similar to that of Howells (1973) in his multivariate, world-wide, cranial studies. The breadth variations were particularly: those measured on the coronal suture (bi-stephanion, bi-coronalia and bi-frontosphenoidale); relative breadth changes affecting the degree of post-orbital constriction (supra-orbital and bi-fronto-temporale); various facial breadths (bi-malar breadth, bi-zygion, bi-zygo-maxillare and interorbital); plus variations in the calvarial breadths on the temporal bones (bi-auriculare, bi-mastoid, bi-porion and maximum cranial). The variations in breadth measurements recorded within Western Australia tended to highlight differences between the southern and eastern samples, with the northern-central samples generally closer to the eastern sample. The most obvious differences were the narrower frontal and broader temporal breadths of the eastern sample when compared to the southern sample.

There were important shape contrasts found in the occipital, parietal, temporal and frontal bones. From the differences recorded for the various chord/arc measurements, it was found that the southern sample parietal and temporal bones were fuller in the sagittal and coronal planes, contrasting to the less rounded northern and eastern parietal and temporal bones. The fullness in the southern sample crania did not extend beyond the lambdoid suture. In fact, relatively, the southern sample occipital bone was the most sagittally flattened, contrasting to the northern and central samples which had a longer arc (relative to the chord) measurement, due to the posterior extension of the inion. The eastern sample was contrasted to the other samples because of frontal bone shape differences. These differences included a marked post-orbital constriction and a relatively fuller antero-posterior frontal curvature. The eastern sample post-orbital constriction was particularly marked when compared to the southern population, which had both a larger bi-frontotemporale and a smaller supra-orbital breadth. Overall it could be seen that the northern and central samples were most similar, having a relatively rounder occipital bone shape; the southern was differentiated because of its parietal and temporal bone shapes, while the eastern sample was separated because of its frontal bone shape.

The first variate of the canonical analysis using 4 Western Australian and 3 coastal New South Wales samples clearly separated the samples from the 2 States (Table 9, Fig. 3). However, although the succeeding variates spread the samples within each State no definitive pattern of inter-relationships emerged. Better separation of Western Australia and New South Wales might be achieved if chord and arc measurements became available for New South Wales. From the small canonical roots in this analysis it would seem that, although good separation is achieved, the differences between the samples are not very great.

The generalized distance analysis of the 7 samples from the 2 States revealed not only a coastal clinal trend from north to south within each State, but also progressive morphometric distance separation between equivalent parts of the 2 States (Table 11). The eastern Western Australian sample was distinguished from all of the other samples. This final result is very suggestive of a north to south migration down the east and west coasts, with the central and the southern samples of the two coasts being longer separated than the northern and hence showing progressively more differences. The isolation of the eastern Western Australian sample, from both the remaining Western Australian and all 3 of the New South Wales samples, could be due to their long-term isolation under environmentally harsher conditions. The isolation of the central Australian desert populations (represented in this study by the eastern Western Australian sample) from northern Western Australian populations was earlier suggested by Banerjee (1963), studying head hair characteristics.

There is still far from unanimity in the views held about the origin of the Australian Aborigines. It is accepted by virtually all authors that there is considerable morphological diversity throughout the continent. However, the basis for this variation is still in considerable dispute. Since 1938 Birdsell has been elaborating a theory suggesting a trihybrid origin (e.g. Birdsell, 1967) and, more recently, Howells (1973) has postulated what might be termed a dihybrid theory. However, the most generally accepted view (e.g. Abbie, 1968; Macintosh, 1965) holds that a single stock colonised Australia and that the variation found is the result of the effects of selection and drift. From late Quaternary studies (e.g. Bowler, 1976) it would seem that the originating stock of the Australian Aborigines arrived in the north of the continent, at least 50,000 and possibly as much as 100,000 years ago, from Southeast Asia (Sahulland). Such a time span of occupation of Australia would seem to be more than adequate for the present level of diversification to have occurred. This view is supported by Kirk (1971) from a review of blood groups, serum proteins and red cell and serum enzyme gene frequency studies. He contends that even 10,000 years would be adequate to account for the present continental variation in these features. In addition, Simmons (1956) has pointed out the improbability of the trihybrid theory because of the absence in the present Australian Aboriginal population of: B, S of MN, rh (cde), rh″ (cdE), Kell (K), and Fy^b of the Duffy group. All of these factors would, improbably, have had to have been absent in each of the 3 hybridising stocks.

The starting point most commonly suggested for the southward migration of the originating stock is Cape York in the northeast of the continent. However, it has also been postulated that entry was in several small groups both at Cape York and also in northwestern Australia (see Abbie, 1969). To reach the southern extremes, which they are known to have reached 30,000-35,000 years ago (see Mulvaney, 1975), man must have been able to cope with the wide range of environmental situations which confronted him on his journey. Nevertheless, it would seem reasonable to postulate that the initial southward migration was made along the most congenial and easily traversed pathways, namely down the east and west coastlines. Such a migration pattern would accord well with the morphometric relationships described in this study. The differences found between the coastal samples could then be the result of distance decay (Wright, 1943), recurrent founder effects (Fix and Lie-Injo, 1975), drift, environmental adaptation, or any combination of these. The morphometric isolation of the Western Australian eastern sample, as suggested above, could be due to adaptation to harsh desert conditions, although, as Mulvaney (1975) notes, conditions were probably very different 50,000 years ago. The numerous complex, linguistic differences found throughout Aboriginal Australia suggest the probable gene flow barriers between the populations of the past (Capell, 1956; Wurm, 1972).

SUMMARY

1. From Western Australia 105 crania (70 male and 35 female) and 53 mandibles (36 male and 17 female) have been studied by both univariate and multivariate analysis. All crania were from known localities and were assumed to be of recent age. Sexing was by the Larnach and Freedman (1964) method.
2. Univariate statistical data for 50 cranial measurements, 22 derived indices and 18 mandibular dimensions were produced separately for males and females. Significant sexual dimorphism was found for most of the measurements. The male data were compared with those of Morant (1927), Hrdlicka (1928) and Wagner (1937). A variety of differences were found.
3. On broad linguistic grounds, a 4 sample subdivision (northern, central, southern and eastern) was made and studied by multivariate analysis using, separately, cranial measurements (whole and subsets), cranial indices and mandibular measurements. The male 50 variable canonical analysis produced the most important result. Coastal variation appeared to be clinal with the inland eastern sample having a more unique set of features. Using canonical variate weights and univariate mean values, it appeared that the parietal, temporal and occipital bone shapes were of considerable significance for differentiating the coastal samples, whilst the eastern sample diverged mainly because of its differently shaped frontal bone. Chord and arc measurements proved most useful when making these comparisons. Breadth measurements were also important in the discrimination.
4. The 4 Western Australian samples were compared with 3 from coastal New South Wales (Freedman, 1964) by multivariate analysis. Using canonical

analysis the first variate clearly separated the groups of samples from the 2 States. Mahalanobis generalized distance indicated that the Western Australian northern and New South Wales northern samples were morphometrically similar; the two central and two southern samples were progressively less similar, both from their own State northern sample and from the equivalent opposite State sample. These data would be in agreement with east and west coast southward migrations from an initial north of Australia originating population.

5. The variation found within and between the Western Australian and coastal New South Wales samples does not call for an hypothesis of more than one originating stock for the Australian Aboriginal population.

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